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The effect of surface heterogeneity on cloud absorption estimates

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[1] This study presents a systematic and quantitative analysis of the effect of inhomogeneous surface albedo on shortwave cloud absorption estimates. We used 3D radiative transfer modeling over a checkerboard surface albedo to calculate cloud absorption. We have found that accounting for surface heterogeneity enhances cloud absorption. However, the enhancement is not sufficient to explain the reported difference between measured and modeled cloud absorption. *INDEX TERMS:* 0320 Atmospheric Composition and Structure: Cloud physics and chemistry; 1640 Global Change: Remote sensing; 3322 Meteorology and Atmospheric Dynamics: Land/atmosphere interactions; 3359 Meteorology and Atmospheric Dynamics: Radiative processes; 3360 Meteorology and Atmospheric Dynamics: Remote sensing. **Citation:** Chiu, J.-Y. C., A. Marshak, and W. J. Wiscombe (2004), The effect of surface heterogeneity on cloud absorption estimates, *Geophys. Res. Lett.*, *31*, L15105, doi:10.1029/2004GL020104.

1. Introduction

[2] Anomalous shortwave cloud absorption is defined as the difference between measured and model-calculated absorption. Regardless of the recent debates about the size of the effect [*Ackerman et al.*, 2003; *O'Hirok and Gautier*, 2003; *Valero et al.*, 2003], there is no doubt that some discrepancies exist between observed and calculated cloud absorption, which tend to be a bias rather than a random error [*Valero et al.*, 2003]. This excess absorption is on the order of 10 W/m^2 [*O'Hirok and Gautier*, 2003; *Valero et al.*, 2003]. Any such bias is of concern since radiative transfer models are tacitly assumed to be unbiased in climate modeling and remote sensing applications.

[3] Numerous efforts have been made to identify potential sources of this shortwave cloud absorption bias, including sampling issues in the observations, measurement uncertainties, cloud inhomogeneity, microphysics optical properties, and aerosol loadings [*Barker*, 1992; *Marshak et al.*, 1997; *Valero et al.*, 1997; *Cess et al.*, 1999; *Knyazikhin et al.*, 2002; *Ackerman et al.*, 2003; *O'Hirok and Gautier*, 2003; *Oreopoulos et al.*, 2003]. Based on high-resolution spectral albedo data, along with a state-of-the-art radiative transfer model [*Li et al.*, 2002], [*Li et al.*, 2003] stated that accounting for the heterogeneity of surface albedo could eliminate the systematic difference between measured and modeled cloud absorption. However, the influence of inhomogeneous surface albedo has been ignored in most radiative transfer models. As a result, up to now, there have been no systematic and quantitative analyses of the effects of surface heterogeneity on cloud absorption estimates. This study aims both to understand how more realistic treatments of surface heterogeneity affect cloud absorption and to examine whether the bias between observed and modeled cloud absorption could be explained by inhomogeneous surface albedo.

2. Approach

[4] We used the Discrete-Ordinate-method (DISORT) [*Stamnes et al.*, 1988], a Monte Carlo method [*Marchuk et al.*, 1980], and the Spherical Harmonics Discrete Ordinate Method (SHDOM) [*Evans*, 1998] radiative transfer models to calculate cloud absorption. Models were set up with clouds over a surface with a checkerboard albedo α (shown in Figure 1), where the complexity of clouds increased from homogeneous to broken. The checkerboard surface was changed from the extreme case of black ($\alpha = 0$) and white ($\alpha = 1$), having the largest contrast, to a black and gray ($\alpha = 0.5$) pattern, which is closer to measured albedos for the Atmospheric Radiation Measurement (ARM) program Southern Great Plains (SGP) central facility. Cloud properties are defined via cloud optical depth τ and single scattering albedo ϖ_0, and cosine of the solar zenith angle (SZA) is denoted as μ_0. For simplicity, molecular scattering, aerosols and gaseous absorption are not taken into account.

[5] Based on energy conservation, cloud absorptance A can be computed from reflectance R and transmittance T as

$$A(\alpha) = 1 - R(\alpha) - (1 - \alpha)T(\alpha), \quad (1)$$

where A, R, and T are all functions of Lambertian surface albedo α, and $(1 - \alpha)T$ presents total surface absorption. Note that A, R, and T are also functions of τ, ϖ_0 and μ_0. For plane-parallel clouds,

$$R(\alpha) = R_0 + \frac{T_0^2 \alpha}{1 - \alpha R^*} \quad (2)$$

and

$$T(\alpha) = \frac{T_0}{1 - \alpha R^*}, \quad (3)$$

where R_0 and T_0 are cloud reflectance and transmittance, respectively, in the case of black surface and R^* is the reflectance of clouds when illuminated from below by

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